A Hybrid Connectionist/Production System Interpretation of Age Differences in Perceptual Learning

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Introduction

In the present paper we will provide a brief discussion of how the appeal to formal models, even used at the conceptual level, can lead to "new directions in cognitive aging research". Following the lead of Salthouse (1988), one of our goals is to encourage efforts to develop and utilize formal models that lead to testable hypothesis concerning age-related cognitive phenomena. Our primary focus is on the explanatory and predictive utility of a specific model for consolidating otherwise confusing age-related practice effects in visual, memory, and hybrid visual/memory search tasks.

Cognitive Aging Research

A review of the literature on differential age-effects in perceptual learning leads to a suggestion of the age independence of search in a consistent mapping (CM) task as well as the age dependence of performance in varied mapping (VM) search tasks[1]. It is important to note that there are two general assertions made in the cognitive aging literature which are relevant to the present discussion. First is the assumption that age-related deficits are due to reductions in controlled processing ability, efficiency of processing, etc. Following this view, VM search effects should differ as a function of age. Second, it is assumed that automatic processes are somehow immune to the deleterious effects of aging. It is true that automatic processes developed prior to senescence may not decline with age, as has been demonstrated in lexical priming studies and the maintenance of Stroop interference effects. However, the assertion that the characteristics of CM search, which lead to the development of automatic processes, do not differ as a function of age has not been agreed upon.

1 Consistently mapped practice involves searching for specific stimuli which always evoke the same response when they occur. For example, in visual search, whenever the target letter 'A' appears in a display it always requires the same response from the subject. When stimuli are variably mapped (VM), i.e., stimuli require responses that constantly change during training, automatic processing does not develop and performance shows little change. For example, in VM training, on one trial the letter 'A' might serve as a target, and therefore require a specified response, while on another trial the letter 'A' would serve as a distractor, and therefore be ignored by the subject. Schneider and Shiffrin (1977) demonstrated that CM practice was a necessary requisite for automatic process development.

In general, previous researchers have inferred that similar CM learning curves early in practice (indexed by a nonsignificant Age X Practice Session interaction) implied that both young and old adults were developing automatic processing at the same rate. The logic of that argument presupposes that all age groups will eventually develop equivalent automatic processing of the CM trained stimuli (e.g., Madden, 1983; Plude & Hoyer, 1981). With very few exceptions (e.g., Salthouse & Somberg, 1982), previous research examining effects of CM training on young and old subjects' performance has provided relatively little practice; that is, the experiments have not been carried out long enough to determine if the automatic processes do actually develop in both age groups.

When extended CM and VM practice is provided to young and old adults, the results are surprising in light of the assumptions existing in the literature. Recently, we (Fisk, McGee, & Giambra, in press; Fisk, Rogers, & Giambra, 1987; Rogers & Fisk, 1988) examined the influence of age on a range of performance measures for consistently mapped and variably mapped visual/memory search tasks. That research extended the previous research examining age-effects in perceptual search tasks by providing extended practice (at least 4,000 CM and 4,000 VM trials), requiring subjects to perform complex semantic-category search tasks, and examining, within-subjects, CM relative to VM performance. In all cases, early in practice, the young and old subjects' performance was similar to that seen in other studies; that is, improving CM search performance for both age groups (measured by reaction time, response time variability, and decreasing comparison slopes) and a nonsignificant Age X Practice Session interaction. However, late in practice, the results suggest that qualitative age differences exist for CM performance; that is, in addition to the fact that older adults are slower (quantitatively different) than young adults, the pattern of performance improvement also differs. Although the older subjects' reaction time decreased with CM practice, there was comparatively little reduction in reaction time, comparison slope, or response variability. These findings hold for simple character search as well as the more complex semantic category search tasks (Fisk & Rogers, 1988). It is also important to note that, with extended practice, the characteristics of the older adults' VM memory scanning and visual search is similar to that of the young subjects. Not only are the patterns of VM search performance equivalent, but the search rate, as measured by the slope of the function relating reaction time to number of comparisons, is also similar (also see Strayer, Wickens, & Braune, 1987).

As noted above, often a plea is made to some amount of reduced mental energy, reduction in controlled processing ability/efficiency, etc. in older adults in order to account for age-related differences in visual/memory search. Given our findings of age-related similarities in VM search (mostly dependent on controlled processing) and age-related differences after extended CM search (indicative of age-related differences in automatic process development), the previous explanations are not appealing. Several questions remain to be answered. Why do young and old adults show equivalent learning early in practice and subsequent divergence late in practice? Why is it that only the young adults show automatic CM target detection? The resolution of these questions must be found in order to explain age-related disruptions, either partial or complete, of automatic process development.

Potential answers to the above questions may be found through the use of a formal model of information processing. The model which seems to account for the apparently discrepant data discussed above is a hybrid connectionist/production system model (Schneider, 1985; Schneider & Detweiler, 1987). The formal modeling approach proposed by Schneider and his colleagues represents a hybrid of two major approaches modeling cognitive mechanisms: connectionist models (for a review see McClelland, Rumelhart, & Hinton, 1986; Schneider, 1987) and production system processing models (e.g., Anderson, 1983). While the utilization of this model for the explanation of empirical data may seem inherently post hoc, the model does make unique and testable predictions concerning age-related effects in visual/memory search. Therefore, we can use this approach not only to consolidate the cognitive aging data already available, but also to drive the direction of future research to further investigate age-related differences.

A Hybrid Connectionist/Production System Model: Conceptually Defined

Schneider's hybrid model proposes two types of learning mechanisms: associative and priority learning. It is assumed that these two different types of learning can occur during CM practice and that both types of learning are necessary in order for the CM trained stimuli to automatically attract attention. Associative learning develops prior to priority learning and is accomplished via a modified Hebb-type learning rule (Stone, 1986) by which an input associatively evokes or retrieves an output message that can be transmitted for additional processing (e.g., "red light" retrieves "press brake pedal"). With associative learning, the learning mechanism changes the connection weights between the input and output information transmissions so that the given input tends to evoke the associated output. Associative learning is responsible for the unitization of memory-sets, categorization (e.g., increasing strength of connections between semantic category exemplars and the higher level category), and increasing connections between target items and required responses. As associative learning develops performance improvements are expected because there is a decrease in the need to pre-load working memory with individual memory set items and the responses associated to those items.

If a deficient associative learning mechanism were the locus of age effects in CM search then old subjects should show no learning during CM search. However, previous studies demonstrate CM learning early in practice for both age groups. Thus the data argue against the associative learning mechanism as the primary source of age-dependent CM search effects. If associative learning is affected to some degree by age, that disruption does not appear sufficient to explain the age differences seen after long-term CM practice.

The other learning mechanism, priority learning, is hypothesized as a mechanism that modifies whether, and how strongly, a given message will be transmitted. Priority learning is an association of a message to a metric of its importance. Messages with high priority are transmitted to higher levels of processing; thus, priority learning provides access of information for follow-on processing (e.g., "red light" - strongly transmits the associated message "press brake" to effect an action). A message will have high or low relevance as a function of its "priority tag". The value of the priority tag is determined by the number of positive transmissions of the message relative to negative or null events associated with the message transmission (e.g., a match response in a search task [a positive event] relative to a negative controlled processing event [processing with no match and no response]). Each positive event results in the priority tag value being incremented and each negative event results in a decrement of the priority tag. Consistent practice would lead to continual incrementing of the priority tag for target stimuli (when detected) and decrementing of the priority for distractor stimuli. Continued CM practice would lead to a segregation of stimuli such that those stimuli with high priority tags (consistent targets) would become "foreground" and stimuli with very low priority tags (consistent distractors) would become "background". Within the hybrid connectionist model, pure automatic processing (processing without control process assistance) is not possible without sufficient priority learning. A combination of both associative and priority learning allows stimuli to be filtered and messages transmitted without control processing assistance; hence, stimuli can automatically attract attention. If "priority" were maintained by simply increasing or decreasing the associated connection weights (i.e., simply associative learning) then a decrement in "priority" would entail a concurrent loss of associative connections thereby implying a memory loss. However, developing a very low priority tag to exemplars of a CM category such as "four-footed animals" does not imply forgetting the meaning of "cat" or that it is an exemplar of the category.

Given the necessity of the priority learning mechanism for the attainment of automaticity, and the apparent inability of old adults to develop automaticity, it seems logical to focus research efforts on this mechanism in an effort to understand age-related decrements in extended-practice experiments. Note that the disruption of the priority change mechanism need not be all-or-none to yield the age effects we have observed. Indeed, a slowing in the priority change process would, to some extent, lead to a slowing in automatic process development. Therefore, although we have provided old subjects with thousands of trials of practice in an effort to allow the development of automaticity (e.g., Fisk, McGee & Giambra [in press] gave some subjects as many as 12,000 trials), it is still possible that thousands of trials more might be necessary if indeed automatic process development is simply slowed as a function of age. Our results have shown that there is an age-related change in the extended-practice CM performance function which may, at the very least, indicate a disruption in the priority learning mechanism.

Conclusions and Future Directions

The current conceptual framework based on the formal model of Schneider and his colleagues can explain many of the previous results of age-related perceptual learning[2] such as: 1) Some amount of learning for both young and old groups of subjects with consistent practice; 2) Qualitatively equivalent performance early in consistent practice but non-equivalent performance with extended consistent practice; and 3) Maintenance of Stroop interference effects or other previously automatized processes such as lexical

2 Note that this model is derived from young subjects' data and has been found to mimic the practice effects which are typically found for both CM and VM practice.

access. Old subjects' improvement in CM search, relative to VM search, is expected given a relatively intact associative learning mechanism. However, the fact that these subjects demonstrate a failure to achieve automatic processing implies a concurrent inability to sufficiently change the priority tag values. Maintenance of automatic processes developed prior to operational failure in the priority mechanism, e.g., color-word Stroop effects (Cohn, Dustman, & Bradford, 1984), arithmetic stroop effects (Fisk & McGee, 1987), and automatic activation of the lexicon (Cerella & Fozard, 1984; Chiarello, Church, & Williams, 1985) would be unaffected by age.

We are therefore proposing that a failure of the priority tag mechanism may accompany aging while the associative learning mechanism remains intact, or at least is not completely disrupted. Three important predictions may be generated from this conceptualization. These predictions are currently being tested in several experiments. First, the model predicts that old adults should be able to unitize (or develop categories of) stimulus sets without the subsequent development of automatism. Behaviorally, this should result in reduced comparison slopes in the absence of other indices of automatic processing of the stimuli as demonstrated by dual-task or stimulus reversal effects. Another prediction of the model suggests that the strength (i.e., the ability to "attract" attention) of target stimuli relative to distractor stimuli should differ across young and old subjects and lead to differences in the pattern of attention attraction for CM trained stimuli as well as differences in various CM/VM target/distractor reversal effects. As predicted by the model, if the priority change mechanism deteriorates as a function of age, less "strength" difference should develop between CM target and CM distractor stimuli due to a lessening ability to modify the priority of consistent targets relative to the consistent distractors. The third prediction is that well-learned, automatized skills developed prior to senescence should be difficult to modify. Again, this would occur because the, once appropriate, high priority of the stimuli/responses would be less modifiable even in the face of new, consistent, contrary practice. This prediction is being tested by examining the attenuation of Stroop interference effects as a function of age and practice.

Although much of the present review has focussed on visual/memory search, the importance of the model is in its apparent ability to account for a variety of results reported in the cognitive aging literature. More importantly, the adoption of this model has allowed us to make strong, testable predictions about age-related performance under specifiable conditions.

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References

Anderson, J. A. (1983). Cognitive and psychological computation with neural models. IEEE Transactions on Systems, Man, and Cybernetics, SMC-13, 799-815.

Cerella, J. & Fozard, J.L. (1984). Lexical access and age. Developmental Psychology, 20, 235-425.

Chiarello, C., Church, K.L., & Williams, W.J. (1985). Automatic and controlled semantic priming: Accuracy, response bias, and aging. Journal of Gerontology, 40, 595-600.

Cohn, N.B., Dustman, R.E., & Bradford, D.C. (1984). Age-related decrements in Stroop color test performance. Journal of Clinical Psychology, 40, 1244-1250.

Fisk, A. D., & McGee, N. D. (1987). Unpublished data.

Fisk, A.D., McGee, N.D. & Giambra, L.M. (in press). Age-related effects on consistent and varied semantic category search performance, Psychology & Aging.

Fisk, A.D., Rogers, W.A., & Giambra, L.M. (1987). Age-related factors affecting automatic process development in visual search: I. Positive and negative responding. Paper presented at the annual meeting of the American Psychological Association, August, New York.

Fisk, A. D., and Rogers, W. A. (1988). Age-dependent influences of memory and visual load in perceptual learning. Paper presented at the Annual Meeting of the American Psychological Association, August, Atlanta.

Madden, D. J. (1983). Aging and distraction by highly familiar stimuli during visual search. Developmental Psychology, 19, 499-507.

McClelland, J. L., Rumelhart, D. E., & Hinton, G. E. (1986). The appeal of parallel distributed processing. In D. E. Rumelhart & J. L. McClelland (Eds.), Parallel distributed processing, Volume 1 (pp 1-44). Cambridge, MA: MIT Press.

Plude, D. J., & Hoyer, W. J. (1981). Adult age differences in visual search as a function of stimulus mapping and processing load. Journal of Gerontology, 36, 598-604.

Rogers, W. A., and Fisk, A. D. (1988). Age-related influences of massed practice, practice type, and practice order on perceptual learning. Paper presented at the Cognitive Aging Conference, April, Atlanta.

Rogers, W. A., & Fisk, A. D. (in press). Age-dependent skills training: Theory, data and guidelines. Proceedings of the Fourth Annual Mid-Central Ergonomics/Human Factors Conference. Champaign, Il: University of Illinois.

Salthouse, T. A. (1988). Initiating the formalization of theories of cognitive aging. Psychology and Aging, 3, 3-16.

Salthouse, T. A., & Somberg, B. L. (1982). Skilled performance: Effects of adult age and experience on elementary processes. Journal of Experimental Psychology: General, 111, 176-207.

Schneider, W. (1985). Toward a model of attention and the development of automaticity. In M. I. Posner & O. S. Martin (Eds.) Attention & Performance XI (pp 475-492). Hillsdale, N.J.: Erlbaum.

Schneider, W. (1987). Connectionism: Is it a paradigm shift for psychology? Behavior Research Methods, Instruments, & Computers, 19, 73-83.

Schneider, W. & Detweiler, M. (in press). A connectionist/ control architecture for working memory. In G. H. Bower (Ed.) The psychology of learning and motivation, Volume 21. New York: Academic Press.

Schneider, W. & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, Search, Attention. Psychological Review, 84, 1-66.

Stone, G. O. (1986). An analysis of the delta rule and the learning of statistical associations. In D. E. Rumelhart & J. L. McClelland (Eds.), Parallel distributed processing, Volume 1 (pp 444-459). Cambridge, MA: MIT Press.

Strayer, D. L., Wickens, C. D., & Braune, R. (1987). Adults age differences in the speed and capacity of information processing: 2. An electrophysiological approach. Psychology and Aging, 2, 99-110.